First Year Tests of an Information Monitoring and Diagnostic System for Large Commercial Buildings

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I. Introduction

Buildings generally do not perform as well in practice as anticipated during the design stage. There are many reasons for this, including improper equipment selection and installation, lack of rigorous commissioning and proper maintenance, and poor feedback on operational performance, including energy performance. This project was conceived to develop and introduce state-of-the-art information technology in buildings in order to enhance substantially building energy performance by continuously improving operations and maintenance (O&M). A detailed description and additional references and quarterly reports on the system are contained in: http://eetd.lbl.gov/EA/IIT/diag/.

The project is being conducted by an interdisciplinary team (see Acknowledgements) to assess the current state of technology, develop a performance monitoring and diagnosis capability, and test it in real buildings. The demonstration site operations staff were carefully selected to ensure that they would participate fully to learn and utilize the capabilities of the new technology.

This paper summarizes recent results from field testing of an Information Monitoring and Diagnostic System (IMDS). The paper contains the following key sections:

- II. **Diagnostic Technology and IMDS Design:** a more detailed description of the scope of the system
- III. **Introduction to the Pilot Demonstration**
- IV. **An Operator's Perspective**: how the building operations staff use the system, what they have found with it, and suggestions on how it could be improved.
- V. **Summary and Future Directions**

II. Diagnostic Technology and IMDS Design

Earlier phases of this project concluded that there are systemic problems associated with the data analysis capabilities available from current Energy Management and Control Systems (EMCS). Today's EMCS are designed for control, with limited capabilities in sensing, archiving, data analysis, diagnostics, and data visualization. The purpose of the current demonstration is to deploy and evaluate the IMDS. The IMDS does not replace the EMCS, but has the following characteristics:

- **Targeted toward sophisticated on-site building operators and engineers** - Several related efforts are targeted toward a remote expert user (Liu, et al. 1997; Honeywell 1998).

- **Designed to be installed permanently** - Several related approaches that are known for ease of use are built around short-term rather than continuous monitoring systems (Waterbury, et al. 1994).
- **High quality sensors** - The sensors are more accurate and reliable than sensors found in most commercial building systems (Sebald & Piette 1997).
- **High frequency archive** - The IMDS archives data each minute. Many current systems do so every 15 minutes or longer, lacking the ability to catch problems such as equipment short cycling (Liu et al. 1997; Waterbury et al. 1994).
- **Top-down design** - The top-down design logically flows from the general whole-building analysis to system and component diagnostics. This is in contrast to bottom-up approaches that attempt to detect performance failures associated with specific individual devices (Hyvarinen & Karki 1996).
- **High-quality visualization** – The on-site data visualization software can handle large data sets (8 points of minute data for 1.5 years in a single graph)
- **Web-based remote access** – A subset of the data visualization tools can be accessed on the web for use from any remote PC.

The IMDS comprises the components depicted in Figure 1. The research team installed the system in the building, with the set of sensors, data acquisition systems, and standard graphics specified. A simple flat-file database has been developed to archive the monitored data. Data from each sensor are archived in the PC server at the demonstration building. The data acquisition and graphical analysis software are located on the PC, allowing the on-site operator and chief engineer direct access to the data. Researchers in several locations have access to the data and the analysis software, allowing them to analyze the building performance and test the automated diagnostic systems. The PC server offers a subset of the real-time analysis graphics from the demonstration site to the public over the Internet. The purpose of the project is to evaluate the benefits of the technology and demonstrate it to interested organizations and potential future service providers such as Energy Service Companies, utilities, and control companies.

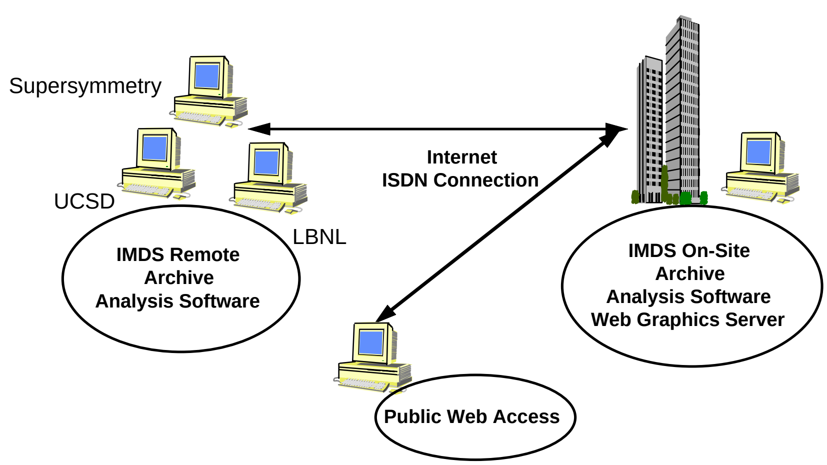


Figure 1. Elements of the Information Monitoring and Diagnostic System (IMDS)

There are difficult tradeoffs between advancing the automation of the diagnostic systems versus designing the system for optimal human-based diagnostics. The current emphasis in this project is to provide reliable and easily interpreted standard performance graphs that the operator can use for “human-based” diagnostics. The initial scoping study showed this to be important prerequestite to the development and introduction of “automated diagnostics”. The operator must trust and believe the data, plus understand the basic principles of any automated diagnostic algorithm or modeling technique.

The IMDS can serve as a robust platform upon which one can deploy automated diagnostic algorithms that may be difficult to deploy in a standard EMCS. The development of automated diagnostics can be justified by the recognition that building systems are becoming more complex over time and are difficult for the average operator to understand (Hyvarinen & Karki 1996). One study found that, after a few months of strong enthusiasm, building operators lost interest in standard energy use plots provided by a utility research project that provided detailed energy data to building operators (Behrens & Belfer 1996). Thus, some automation of diagnostics is needed to generate alarms that can tell an operator when the diagnostic system has identified a performance problem or deviation from normal operation. When such an alarm is sounded, the operator can than query the standard plots to look at the nature of the problem.

An EMCS typically focusses on scheduling and controlling building HVAC systems, including air temperatures and flows and monitoring zone conditions. By contrast, the IMDS focusses on measuring energy, weather and water-side variables (temperatures, pressures and flows). EMCS sensors are frequently not adequate due to poor durability (frequent failures or falling out of calibration) and accuracy (e.g. measuring flow rates accurately is crucial for efficiency analysis but typical systems either do not measure flow rates or do so with limited accuracy).

The installed system consists of about 50 points and several dozen calculated, or virtual, points (such as load or efficiency) which are based on sensors such as high-grade thermistors, power meters, magnetic flow meters, and aspirated psychrometers. The scope of the IMDS is listed in Table 1.

Table 1. Scope of Information Monitoring and Diagnostic System (IMDS)

System to be Evaluated	Number of Physical Points
Whole Building	1
Two Chillers	19
4 Pumps	8
One Cooling Tower	12
One Air Handler	11
Local Micro-Climate	2
Miscellaneous (lights & plug)	4
Total	57

III. Introduction to the Pilot Demonstration

The building selected for the demonstration is a 100,000 sqft office at 160 Sansome Street in San Francisco, also known as the Hong Kong Bank Building. The building is about 30 years old, with two 200-ton chillers that are also 30 years old. LBNL has conducted bi-weekly interviews of the operations staff to evaluate how the system is used. The building operators are extremely happy with the IMDS and have utilized most of its features. The on-site operator (Glen Starkey) uses the system to track critical system temperatures and other operating parameters on a real time basis. The property management company's chief engineer (Fredric Smothers, our key partner in the innovation research) uses the remote web system (now available from his home) nearly every day.

The primary benefit of the IMDS has been to improve the use of the current controls. Anecdotal evidence suggests that the building is more comfortable than in recent years. Complaint calls have reportedly been reduced from an average of 20 per month to 3 per month. This finding is under further investigation through a review of the historical complaint logs. The research team is also in the process of developing a cost-benefit analysis of the IMDS based on the first year results. The following section provides some of the operator's own words regarding the use and value of the system.

IV. An Operator's Perspective

IV.1. Overview

As building operators, we were very excited to be chosen to participate in the IMDS project. We looked forward to having much more data about our equipment and our operation, and the ability to make better decisions, not only operationally but also in new equipment selection. The ability to have access to the data, and share it with others, over the Internet was exciting, and a bit daunting.

The system was installed about a year ago, and we were given access to the system in July of 1998. During the initial installation and commissioning of the system, two significant design problems were discovered; these problems had existed since initial construction in 1966, and had been undiscovered until sensor discrepancies appeared in the commissioning process. This project was not a part of our regular responsibilities as building operators and property managers. Time had to be robbed from other duties to work on the system. Tasks such as learning the new software, and learning a few UNIX commands took a far back seat to the day-to-day responsibilities of operating and maintaining buildings.

We finally started using the system in earnest about December of '98; after the “cooling season” in San Francisco. The timing is important, in that the installed sensors did not measure the heating system in the building. Our first real exposure was confined to monitoring the main supply fan and its temperature and static pressure controls. We have not yet reached another cooling season in San Francisco. Nevertheless, we have gathered some good data on the fan systems, improved control algorithms, and identified areas that need more work and attention to detail. The research team has presented some good ideas that will be implemented as budgets permit.

The IMDS system has given us a glimpse of a possible future for the control of office building operation. We currently have far more data to work with, than time for finding out what the data tells us. We are beginning to envision tools that would “pre-digest” large portions of the data, allowing us to focus our attention on potential problems rather than attempting to swallow the entire sea of data.

IV.2. How We Use the IMDS

The software for the IMDS is in two parts. First, on the host server is the Electric Eye software for on-site reduction of large amounts of data. This software was designed to perform statistical analysis of large building performance data sets, such as examining the relationship between key parameters. That is not how we use this software.

Because of its graphical data presentation capabilities, the Electric Eye software represents a new paradigm in operator interface for energy management systems. The existing system in the building presents a text list of related points (an unchangeable list), with readings taken about once a minute. System delays can make some data two or three minutes old. The Electric Eye display presents not only the information, but has the ability to graph many system points simultaneously. This allows the operator to gather together “on-the-fly” those points that are currently relevant, view their past history, see the trend direction, compare this data with other days of similar operation, and use the independent variables as leading indicators of system performance. More importantly, when it doesn't perform as expected, the operator is immediately aware that his mental picture may be in error.

The second element of the IMDS, also located on the host, is the web server software that presents a more limited view of the building systems over the Internet. A system inadvertently left on, a missed key-stroke in a programming sequence, a switch left in the wrong position – all are readily apparent from a distance. The potential for remote operation and, more importantly, remote diagnosis, is quite obvious. We currently access the web site remotely to review and check operation, both to recap events and for real-time analysis (particularly of system start-up).

IV.3 What Have We Found

Because we were not running a chiller when we first started looking at the system, we concentrated our learning process on the main fan system. Figure 2, from January 21, 1999, illustrates our first finding.

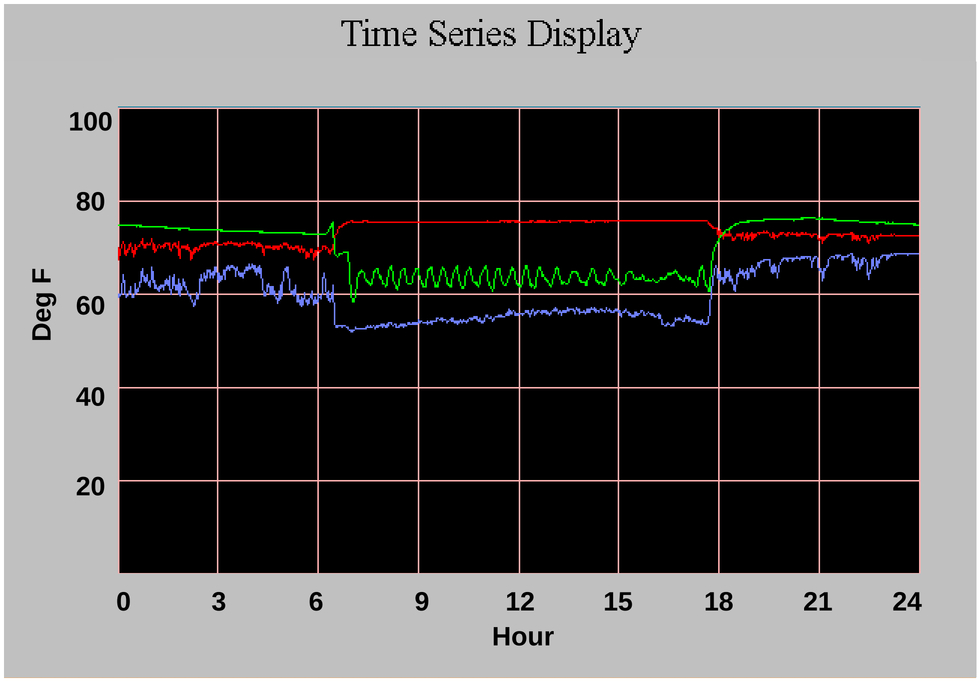


Figure 2. Supply, Mixed, and Return Air Temperatures for January 21, 1999 (from Web-based graphical analysis tool).

With no chiller in operation, it could only be the dampers that were oscillating. The only tool we had to analyze this was a listing of the code in the existing EMCS. We finally found the routine that was incorrect, obtained the instructions from the vendor to change the gains, and cut and tried various combinations of gain parameters. A more recent display (Figure 3, June 1) shows the results of our work on a good day.

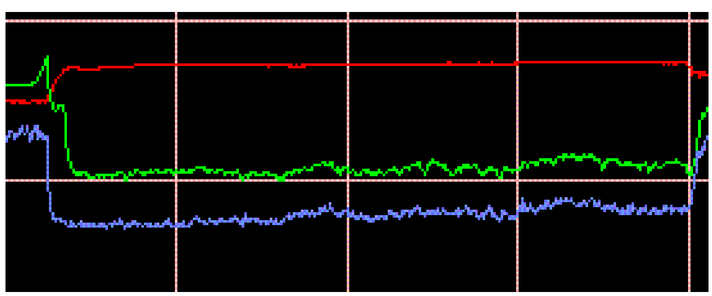


Figure 3. Supply, Mixed, and Return Air for June 1, 1999

We next turned our attention to the control of the inlet guide vanes by the static pressure control system. From the very beginning, we had trouble understanding the data (Figure 4).

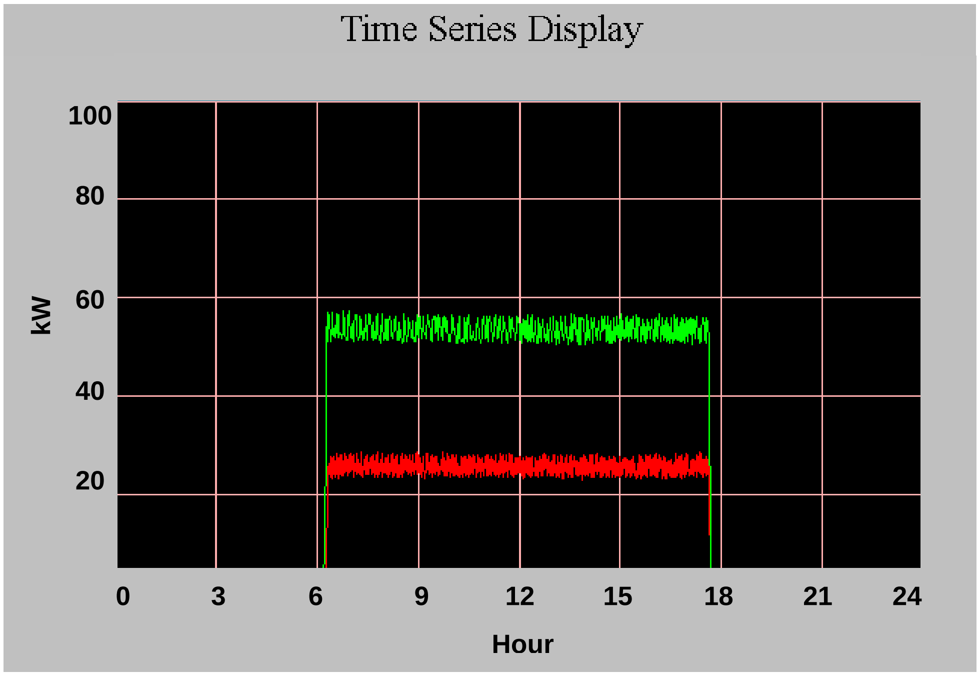
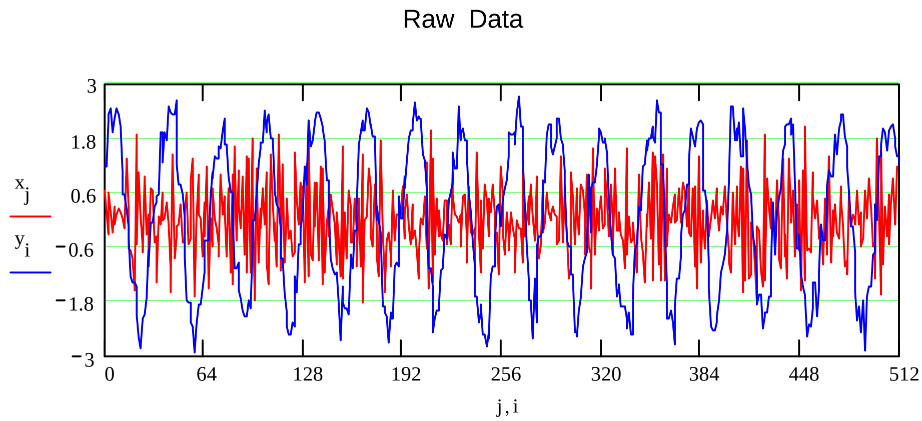


Figure 4. Supply and Return Air Fan Power Oscillations

These oscillations are approximately five percent, plus or minus, for both the supply and return fan true kW. We have tried many experiments to isolate the problem. In the course of testing, we even ran real-time sessions on the Internet between the building and Singapore to test the system at very high data rates. We borrowed instrumentation from the PG&E Energy Center's Tool Lending Library. After many hours of testing various combinations of fans, drives, etc., we believe we have an answer. A rework of the belts on the return fan showed a significant reduction in the oscillation for this fan.

Using a combination of data from the IMDS and a meter from the Tool Lending Library, we derived the following before (blue) and after (red) readings of the return fan power usage.



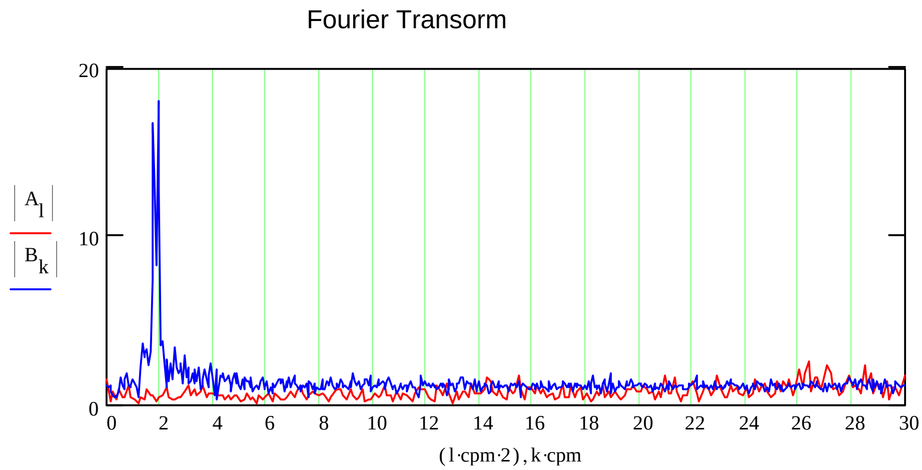


Figure 5. Fourier Transform of Return Air Fan Power Oscillations Before and After Belt Maintenance.

The Fourier spectrum clearly shows the difference that was achieved by just adjusting and re-aligning the belts. Our next experiment will be to do the same work on the supply fan. This will help us verify the information that we have obtained.

These are just graphic examples of how the IMDS has been used to date. We have spent a great deal of time re-examining our basic assumptions about our control algorithms and operational practices. As we get into the cooling season in San Francisco, a whole new area of work awaits us.

In the next year, we hope to use the data from the IMDS to assist in the selection of new chillers to replace the 1966 vintage R-11 machines currently in use. We are also hoping to install a new energy management system. This new system <u>will</u> incorporate many of the features of the IMDS, especially in the ability to gather and display data in this graphical format. Another important feature will be an open and easy access to the control algorithms so that they may be changed and adjusted as new data is acquired.

IV. 4 What Would We Do Differently

The miracle of a dancing bear is not how well it dances, but that it dances at all. The operator interface of the IMDS is not as intuitive as it could be if designed in a standard Windows environment. It does not have standardized graphs, or the ability to create standard graphs for more rapid selection of points (although these enhancements are in progress).

In the San Francisco environment, our cooling season is not terribly long. We use approximately 800 equivalent full load chiller hours. The heating season is also an important factor in our energy usage. Inclusion of the heating side of the plant would be very useful in a California coastal climate.

Above all, it does not incorporate any 'fixed' diagnostics. To be fair, it was designed to accommodate any form of analysis. And we are not entirely sure what diagnostics would be useful as yet. (I don't know any choreographers for bears, and I do not wish to be the director!)

IV. 5. Conclusion

We at 160 Sansome have been very privileged to be chosen to participate in this project. We have learned a tremendous amount from the process, both about our systems, and the new ways of looking at data. The process has forced us to re-examine many of our beliefs. Over the next year, we will be implementing many changes, some of which have already been suggested by the research team. There will be direct energy savings from this project. More importantly, the changes in thinking about the operation of the building will improve our operation and our energy efficiency in general. These ideas will percolate throughout the operating community and result in fare more significant savings in the long run.

V. Summary and Future Directions

The primary objective of this project is to introduce state-of-the-art building monitoring and diagnostic information systems into Class A buildings for use by sophisticated building operators. This objective is based on background research, which suggests that the proposed system meets the needs of operators and that they support the system we've designed. The concept is to deploy a permanent system to assist in continuous improvements in O&M to reduce energy use and operating costs. Our overall goal is to work with building owners and property managers in demonstrating the cost effectiveness of the proposed diagnostic system, thereby creating a market demand for such technology. We hope to demonstrate that the system could be cost effective when commercialized by the private sector.

The IMDS demonstration is oriented toward deploying the basic infrastructure for an advanced information system, including field tests of initial applications. This demonstration will allow the controls industry to examine the value of such systems that greatly exceed today's current EMCS technology. Such a system is the starting point for more advanced, automated, diagnostics. LBNL will be developing a chiller efficiency model based on PG&E's Cool Tools model. Manufacturer's data will be used to develop baseline performance curves for the chillers at 160 Sansome using the Cool Tools curve fitting procedures. We will evaluate the feasibility of deploying the algorithm directly in the software used at the site.

The diagnostic system described here measures various building systems and components to provide feedback on building performance. The users of such systems will be building operators and property managers. The project involves working with innovative experts a) to assist in developing new technology and b) to use them and their peer groups to develop a technology pull strategy as they provide feedback on the technology. The suppliers could be electric utilities, other third-party experts such as ESCOs, or control companies. The service would ideally be paid through savings in the operating budget. It could reduce operating costs and make their spaces potentially more comfortable.

VI. Acknowledgments

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